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Optimization of the Process of Osmo – Convective Drying of Edible Button Mushrooms using Response Surface Methodology (RSM)

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Abstract**—**Simultaneous effects of temperature, immersion time, salt concentration, sucrose concentration, pressure and convective dryer temperature on the combined osmotic dehydration - convective drying of edible button mushrooms were investigated. Experiments were designed according to Central Composite Design with six factors each at five different levels. Response Surface Methodology (RSM) was used to determine the optimum processing conditions that yield maximum water loss and rehydration ratio and minimum solid gain and shrinkage in osmotic-convective drying of edible button mushrooms. Applying surfaces profiler and contour plots optimum operation conditions were found to be temperature of 39 °C, immersion time of 164 min, salt concentration of 14%, sucrose concentration of 53%, pressure of 600 mbar and drying temperature of 40 °C. At these optimum conditions, water loss, solid gain, rehydration ratio and shrinkage were found to be 63.38 (g/100 g initial sample), 3.17 (g/100 g initial sample), 2.26 and 7.15%, respectively.

Keywords**—**Dehydration, Mushroom, Optimization, Osmotic, Response Surface Methodology

I. INTRODUCTION

DEHYDRATED vegetable products are suited to a broad range of food formulations including instant soups, snack seasoning and meat and rice dishes [1]. The consumer demand has increased for processed products that keep more of their original characteristics. The combined use of osmotic treatment and convective drying not only greatly enhances the drying rate, but may also improve the final product quality. Osmotic dehydration can be used as an effective method to remove water from vegetable issues, while simultaneously introducing solutes in the product. As explained by Torringa *et al.* [2], osmotic treatment of halved mushrooms with salt solution of 10 up till 20% (w/w) concentration at moderate temperatures up to 45 °C gives a removal of 30% of the total available moisture and a salt gain up to 0.5 g salt/g initial dryer matter

Since Ponting *et al.* [3] first suggested a process for 50% reduction in weight of apples by osmotic dehydration prior to vacuum drying process, osmotic dehydration is being widely used in processing industries of fruits, vegetables, meat and fish. Lenart [4] showed that two most important parameters of the process are: time and temperature. The effect of the concentration and temperature of the osmotic solution has been studied in considerable detail and it has been shown that the rate of osmotic dehydration increases with an increase in both parameters.

Some other technologies are also introduced by Shi *et al.* [5] into osmotic dehydration process such as combined method of heating and vacuum osmotic dehydration. Some authors [6, 5] pointed out; higher dehydration rate could be obtained under low pressure system. Vacuum treatment has significant effect on the water transfer during the osmotic dehydration. Vacuum osmotic dehydration technology makes possible to use lower solution temperature to obtain higher water loss rate so as to obtain good quality of dehydrated product [5]. As discussed by Zhao and Xie [7], vacuum impregnation has broad applications in fruit and vegetable processing and provides many unique advantages. The water loss, weight loss and °Brix increase during vacuum pulse osmotic dehydration of cantaloupe were predicted by the selected models. The optimum condition can be predicted by RSM (Response Surface Methodology) and conventional graphic methods [8].

The wide variation in the physical nature of fruits affects their osmotic behavior and the state of the final osmotically dehydrated products [9]. It's mentioned elsewhere [10, 11] The transport properties will depend on tissue properties especially on the intercellular space present in the tissue.

In this research, Response Surface Methodology (RSM) was used to determine the optimum osmotic pre-treatment conditions for convective drying of edible button mushrooms. Osmotic solution temperature, immersion time, salt concentration, sucrose concentration, pressure and convective drying temperature were the parameters investigated with respect to water loss, rehydration ratio, solid gain and shrinkage. Experiments were designed according to Central Composite Design with six factors each at five different levels.

II. MATERIALS AND METHODS

Fresh edible bottom mushrooms from local farm with the initial humidity of 91% (±2) were used for experiments. The humidity was measured using AOAC [12] test method in the

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atmospheric oven and temperature of 102 (±2) °C. Sucrose (commercial sugar) and food grade citric acid were purchased from local market. High purity sodium chloride was purchased from a local producer. The osmotic solution was prepared by blending different proportions of sucrose and sodium chloride with tap water. Citric acid content of the osmotic solution was kept at 1% (w/v) for the all experiments to prevent browning of slices during the experiments.

According to the results of initially carried out pretests, solution temperature (25-40°C), immersion time (120-300 min), salt concentration (0-15%), sucrose concentration (40-60%), pressure (500-700 mbar) and drying temperature (30-60°C) were investigated to determine their effect on water loss (WL), solid gain (SG), rehydration ratio (RE) and shrinkage (SH) of edible button mushrooms. Experiments were designed by JMP software version 7 according to Response Surface Methodology and Central Composite Design. Four replications for each experiment on osmosis as well as drying process were carried out and average value was reported.

The mushrooms were halved manually with stainless steel knives after which they were weighed and layered in the especial basket and immersed in the osmotic solution which, was already heated up to the designed temperature. The initial ratio of osmotic solution to mushrooms was kept at 10:1 and consequently the variations in the concentration of osmotic solution during the experiments considered negligible.

At the start of treatment, the system was placed into a vacuum oven under the designed pressure for 10 minutes. Then the osmotic dehydration continued under atmospheric pressure. At the designed time intervals, the samples were withdrawn out of solution and washed with tap water for 30 seconds. After removing their surface water the slices were weighed and put in the convective dryer until their final humidity decreased to 7%.

The water loss (WL) and solid gain (SG) were calculated on the basis of the general balance of concentration driven mass transfer between the liquid and solid phase. Based on this, the following equations suggested by Nsonzi and Ramaswamy [13] were used for estimation of WL and SG.

$$WL = \frac{w_0 x_0 - w_t x_t}{w_0} \times 100 \quad (1)$$

$$SG = \frac{w_t s_t - w_0 s_0}{w_0} \times 100 \quad (2)$$

where:
WL: water loss (%),
w_0: mass of mushrooms sample at time 0 (gr)
w_t: mass of dehydrated mushrooms sample at time t (gr)
x_0, $x_{t,}$: moisture fraction of mushrooms at time 0 and after dehydration for a contact time of t respectively (gr/gr)
s_0,
s_t : solid fraction of mushrooms sample at time 0 and after dehydration for a contact time of t respectively on dry basis (gr/gr)

Rehydration ratio of the dried mushroom samples were determined by mixing about 2 g of sample with 30 ml of distilled water in an 80 ml beaker. It was allowed to rehydrate for 2 h at room temperature. Using Ertekin and Cakaloz [14] method, the end of rehydration period, the water was drained and the weight of moisture content was determined. The rehydration ratio was calculated as follows:

$$RE = \frac{w_r}{w_d} \quad (3)$$

Where:
w_r: mass of rehydrated sample (g) ;
w_d: mass of dried sample (g)

The shrinkage of dried samples was calculated by determining the volumes of initial fresh mushrooms and final dried samples. The initial and final volume of slices was measured by immersing them in the toluene of a precisely graduated measuring cylinder and recording the movement of volume. The shrinkage was calculated as follows:

$$SH = \frac{v_0 - v_f}{v_0} \times 100 \quad (4)$$

v_0: volume of untreated mushroom samples (ml),
v_f: volume of mushroom samples dehydrated by osmotic treatment (ml)

Multiple linear regression was used to fit the experimental data to polynomial equation of second order. Surface response and contour plots were generated from models. The contour plots for all responses were overlaid to locate the optimum region. JMP v. 7 software was used for "Design of Experiments" and analyzing the results.

III. Results

The results of osmotic treatment together with the designed experiments by RSM are shown in table 1

System responses were varied at the following limits: water loss: 27.31 to 61.05 (gr/100 gr initial sample), Solid gain: 3.36 to 13.66 (gr/100 gr initial sample), Rehydration ratio: 1.46 to 2.45 and shrinkage: 9 to 40%.

The surface profilers for water loss are drawn as a function of two factors: water loss (WL) versus operation pressure (OP) and salt concentration (SC), Fig. 1; and water loss versus immersion time (IT) and salt concentration (SC), Fig. 2.

The surface profilers for solid gain versus salt concentration and immersion time and for rehydration ratio versus salt and sucrose concentrations are drawn in Fig. 3 and Fig. 4. Any increase in sucrose concentration up to 55% caused to an increase in solid gain, while above 55%, solid gain decreased by an increase in sucrose concentration.

Rehydration ratio is an important parameter of dried mushrooms which was affected considerably by individual variations in immersion time and salt concentration, but their simultaneous effects on rehydration ratio especially at high salt concentrations can't be specified from this figure. An optimization is needed to find the best operational conditions.

We found no direct relationship between shrinkage of samples and the system conditions.

TABLE I
DESIGNED EXPERIMENTS ACCORDING TO CCD AND MEASURED RESPONSES OF SYSTEM

No	ST (°C)	IT (min)	SC (%)	SuC. (%)	OP (mbar)	DT (°C)	WL* (%)	SG* (%)	SH* (%)	RE*
1	25	210	8	50	600	45	37.7	5.2	10	1.6
2	30	178	5	46	565	50	35.5	5.5	33.3	1.93
3	30	178	5	46	635	40	34.2	4.3	10.5	1.76
4	30	178	5	54	565	40	39.1	7.3	34	1.89
5	30	178	5	54	635	50	30.0	4.4	34	1.86
6	30	178	10	46	565	40	39.2	10.6	34	1.73
7	30	178	10	46	635	50	45.8	6.4	34	1.82
8	30	178	10	54	565	50	39.1	5.6	34	1.73
9	30	178	10	54	635	40	53.9	8.6	34	2
10	30	242	5	46	565	40	33.2	3.4	34	3.09
11	30	242	5	46	635	50	41.2	3.7	34	1.95
12	30	242	5	54	565	50	40.7	7.8	34	2.14
13	30	242	5	54	635	40	39.5	6.0	34	1.79
14	30	242	10	46	565	50	41.9	11.4	34	1.8
15	30	242	10	46	635	40	55.0	4.1	34	1.88
16	30	242	10	54	565	40	56.0	12.2	34	1.77
17	30	242	10	54	635	50	50.5	6.5	11	1.84
18	33	120	8	50	600	45	43.1	4.6	9	1.96
19	33	210	0	50	600	45	39.9	7.6	34	1.74
20	33	210	8	40	600	45	39.7	3.7	11	1.56
21	33	210	8	50	500	45	38.7	6.7	9	1.93
22	33	210	8	50	600	30	45.7	12.6	40	1.89
23	33	210	8	50	600	45	41.1	7.4	11	1.72
24	33	210	8	50	600	45	42.4	7.7	34	1.83
25	33	210	8	50	600	60	53.9	6.6	11	1.9
26	33	210	8	50	700	45	55.7	8.9	40	1.89
27	33	210	8	60	600	45	52.0	7.0	21.8	1.86
28	33	210	15	50	600	45	51.8	8.0	11	1.59
29	33	300	8	50	600	45	50.9	4.6	9	1.65
30	35	178	5	46	565	40	35.4	5.5	11	1.83
31	35	178	5	46	635	50	33.6	5.9	10	2.12
32	35	178	5	54	565	50	28.1	5.4	10.5	1.87
33	35	178	5	54	635	40	27.3	13.7	9	1.65
34	35	178	10	46	565	50	48.3	4.4	11	1.84
35	35	178	10	46	635	40	52.0	5.2	34	2.73
36	35	178	10	54	565	40	45.5	6.6	10	1.86
37	35	178	10	54	635	50	49.7	10.6	40	2.45
38	35	242	5	46	565	50	47.4	5.7	34	1.94
39	35	242	5	46	635	40	43.0	8.2	9	1.77
40	35	242	5	54	565	40	43.8	11.0	10	1.82
41	35	242	5	54	635	50	46.6	4.5	40	1.89
42	35	242	10	46	565	40	43.0	6.5	10	1.83
43	35	242	10	46	635	50	51.5	6.6	11	1.82
44	35	242	10	54	565	50	52.7	12.2	34	1.46
45	35	242	10	54	635	40	61.1	12.5	11	1.85
46	40	210	8	50	600	45	50.4	5.7	9.5	1.73

* Values of responses are mean of four repetitions

ST: Solution Temperature, IT: Immersion Time, SC: Salt Concentration, SuC: Sucrose Concentration, OP: Operating Pressure, DT: Convective Dryer Temperature

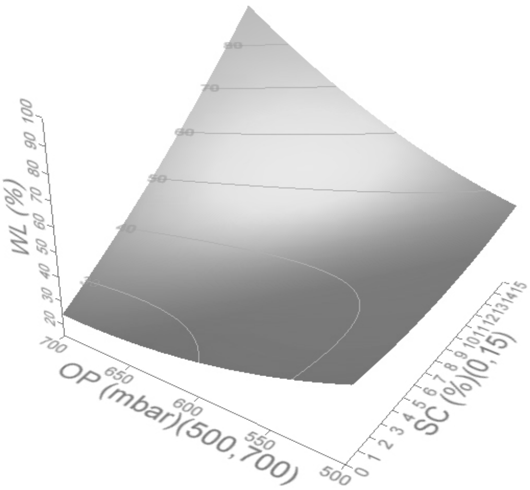

Fig. 1 Effect of operating pressure (OP) and salt concentration (SC) on water loss (WL)

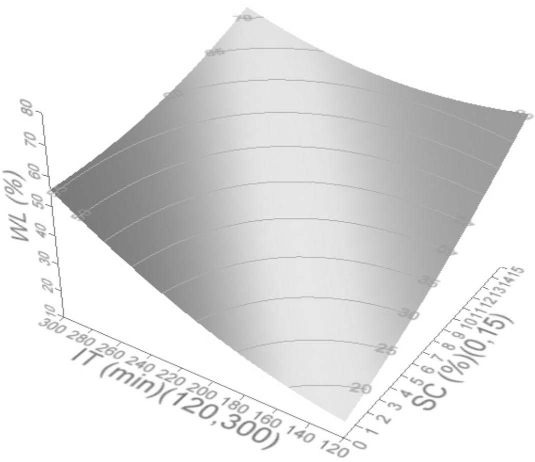

Fig. 2 Effect of immersion time (IT) and salt concentration (SC) on water loss (WL)

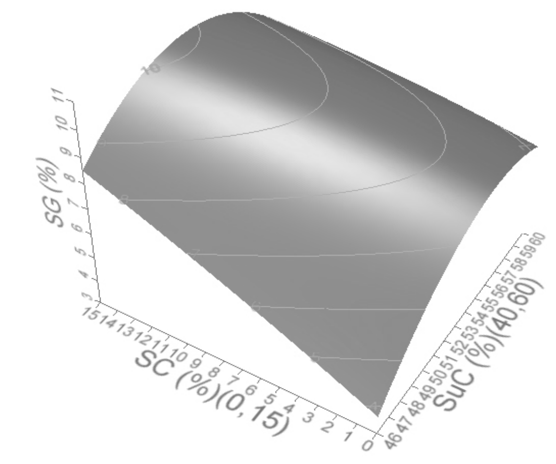

Fig. 3 Effect of salt concentration (SC) and sucrose concentration (SuC) on solid gain (SG) of mushrooms

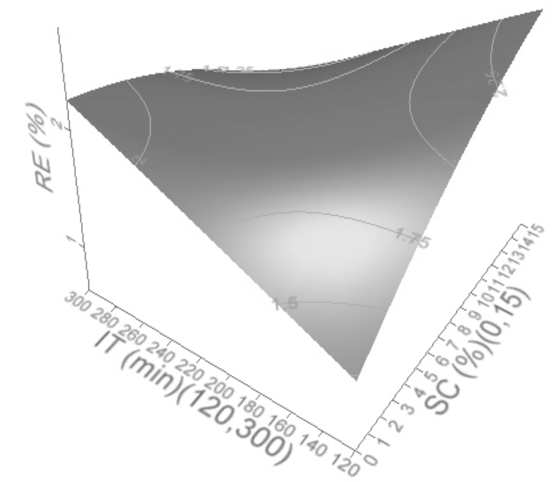

Fig. 4 Effect of salt concentration (SC) and immersion time (IT) on rehydration ratio (RE)

IV. Discussion

From Fig. 1 it can be noted that an increase in salt concentration or a decrease in operating pressure leads to an increase in water loss, although water loss is affected by salt concentration more than by a lower operating pressure. This is in agreement with results presented by Mujica *et al*. [15] for apple. Comparing Fig. 1 and Fig. 2 shows higher effect of immersion time on water loss than operating pressure. An increase in salt concentration and immersion time leads to an increase in water loss. As discussed, at the start of treatment, the system was placed under the designed vacuum for 10 minutes and then the osmotic dehydration continued under atmospheric pressure. At these conditions the applied vacuum didn't show a significant effect on the osmotic treatment.

Graphical optimization was adopted to determine the optimum conditions for initially vacuumed osmotic dehydration of edible button mushrooms. The contour plots for the desired conditions were overlaid and the region that satisfied all constrains (high water loss and rehydration ratio; small solid gain and shrinkage ratio) was selected as optimum conditions. The low limit and high limit of each parameter for contour plot was defined as follows in order to reach to the highest performance and best possible quality.

Water loss: 63-65 (gr/100 gr initial sample),
Solid gain: 2.5-3.5 (gr/100 gr initial sample),
Shrinkage 0-8% and
Rehydration ratio: 2.5-3.5

Corresponding values of different parameters, which satisfied the above performance and quality criteria of dried mushrooms, were extracted from the contour plot to be: Osmotic solution temperature of 39 °C, immersion time of 164 min, salt concentration of 14%, sucrose concentration of 53%, operating pressure of 600 mbar and convective dryer temperature of 40.8 °C. Four new experiments were performed under these conditions and the average result was recorded. Table 2 compares the predicted and experimental amounts of dehydrated mushroom parameters. From this table it can be denoted that water loss, solid gain and shrinkage have been improved properly. According to table 1, rehydration ratio values have mostly been below 2, nevertheless, it is increased to 2.26 for optimum conditions which are mentioned in table 2.

TABLE II
CALCULATED AND EXPERIMENTAL VALUES OF SYSTEM RESPONSES AT OPTIMUM CONDITIONS

	Water loss (%)	Solid gain (%)	Shrinkage (%)	Rehydration Ratio
Predicted value	64.73	2.2	5.94	2.68
Experimental value	63.38	3.17	7.15	2.26

A summary of the achieved results are as follows:

- The water loss, solid gain, shrinkage and rehydration ratio during osmotic dehydration of edible button mushrooms can be predicted by selected models.
- The RSM and contour plot analysis are effective in determining the optimum zone within the experimental region selected for this process.
- The optimum conditions are osmotic solution temperature of 39.2 °C, immersion time of 164 min, salt concentration of 14%, sucrose concentration of 53%, an operating pressure of 600 mbar and convective dryer temperature of 40.8 °C.
- At the optimum conditions, the water loss of 63.38 (gr/100 gr initial sample), solid gain of 3.17 (gr/100 gr initial sample), shrinkage of 7.15% and rehydration ratio of 2.26 can be achieved.

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